24 GHZ Aircraft Scatter QSO over 566 km

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A successful QSO, even though it did take some 3 hours, but we did learn a lot about accurate beaming and allowing for aircraft elevation as well as how critical beaming angle is for atmospheric losses. We consider this QSO was only possible because:

- The Precipitable Water (PW) was low and there were no clouds
- The aircraft needed to be large – at least larger than the typical domestic 737 or A320.
- The aircraft need to be flying at close to 40,000 ft so as to provide a higher beaming angle and thus reduced atmospheric losses.

To our knowledge 24 GHz aircraft scatter has never been done anywhere before in the World.

Background

Up to now the best distance we have done on 24 GHz aircraft scatter is 461 km using JT65c. At that time VK7MO was running 4 watts to a 47 cm dish and VK3HZ was running 1 watt to a 30 cm dish. Since then VK7MO has upgraded to 20 watts and a 1.14 metre dish (EME class station) and VK3HZ has upgraded to 4 watts and a 60 cm dish. In terms of being able to detect something one way there is an improvement from 1 to 20 watts or 13 dB in power plus a total of around 14 dB in antenna gain. Also for the 461 km QSO VK7MO's 47 cm dish was not properly illuminated and the gain down around 4 dB. So all up there should have been an improvement in system performance to detect a signal of over 30 dB and about 23 dB improvement in our ability to complete a QSO one way. It is difficult to compare the ability to have a QSO between JT65c and ISCAT-B as while JT65c has more sensitivity ISCAT-B can decode very short bursts which would not be decodable with JT65c. However, it is possible to compare our ability to detect a signal where there has been over 30 dB improvement. Despite this improvement nothing at all was detected in tests at 723 km, 711 km, and 625 km. This was over paths that had a good common window and on which SSB aircraft scatter QSOs were possible on 10 GHz.

Compared to 10 GHz the big difference is atmospheric absorption. At the surface under good conditions atmospheric absorption, due mainly to water vapour, can add at least 0.1 dB/ km which would add over 50 dB to the path losses – but as most of the path to and from the aircraft is at high elevation where losses due to water vapour are much reduced it was considered these losses should be much less than 50 dB. Our first thought was to run a check on the equipment and a test over 281 km gave good tropo signals on JT4f and by beaming upwards to aircraft we conducted an easy aircraft scatter QSO. With the knowledge that the systems was working on aircraft scatter the next step was to choose an intermediate distance between the 461 km that had worked and the 625 km that failed. And thus we tried this test over 566 km which while it worked was very close to the limit as it took some 3 hours to complete a QSO.

While we have picked up system performance significantly most of this is due to increased antenna gain and the downside is that this requires much more accurate beaming in both azimuth and elevation which is another potential reason for the failures with the longer distance attempts.

Another possible reason for the weaker signals at 24 GHz compared to 10 GHz is the fact that the structure of the scatter pattern in terms of lobes breaks up into more lobes in proportion to frequency. So if, for example, we are working on the 3rd lobe down in the vertical plane at 10 GHz this becomes the 7^{th} lobe down at 24 GHz and much weaker. It is in part made up for by the fact that the main lobe is increased by the square of frequency or about 7 dB at 24 GHz and as a consequence the side lobes are also increased. But this issue is accentuated further in the horizontal plane such that useful lobes will be limited to a much narrower scatter angle -- this affect seems to be evident in the Doppler results which we discuss below.

Conditions

PW Adelaide 8.2 mm
PW Melbourne 9.7 mm
As the path would be inland, the Woomera PW of 6.8 mm might be more representative but it still looks like the PW for the path would be in the range 7 to 8 mm which is very low. And the elevations of 700 metres at VK3HZ and 400 metres at VK7MO would have further reduced the effective PW.

No clouds at either end.

Equipment
VK7MO 20 watts to a 1.14 metre dish
VK3HZ 4 watts to a 600 mm dish

Beaming Angles
Given the large antenna gains and narrow beamwidths it was necessary to track the aircraft in elevation as well as have very accurate azimuths. Based on the normal Adelaide to Melbourne flight path the following table was used for elevation tracking:

Expected Crossing Distance	30 k ft (degrees)	35 k ft (degrees)	40 k ft (degrees)
VK7MO 240 km	1.4	1.7	2.0
VK3HZ 320 km	0.5	0.8	1.0

While initially the aircraft followed this flight path they later changed to a more southerly route out of Adelaide (possible because of a wind change and take-off to the South) and this increased the crossing point from VK7MO to around 300 km and that from VK3HZ to around 260 km and it was necessary to make adjustments on the run (not allowed for in our prepared table) to correct for the estimated new elevations.

It can be roughly stated that a doubling of the elevation angle will halve the absorption losses. As can be seen from the above table the average elevation for both ends is 1 degree at 30,000 ft rising to 1.5 degrees at 40,000 ft which would roughly imply a 50% increase in losses if the aircraft is at the lower height. Thus if for example the actual atmospheric losses were about 20 dB (assuming most of the path is at high altitude so not the full 50 dB) for an aircraft at 40,000 feet they would rise to 30 dB for an aircraft at 30,000 ft and thus the need to use only high flying aircraft.

Results

Good data highlighted in Green and good Doppler highlighted in Yellow. Comments in **bold Red**

UTC Date: 2014 Sep 20

As Rxed by VK7MO

234430 Transmitting: ISCAT- VK3HZ VK7MO

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First indication of a signal, over an hour later – several aircraft crossed with nothing

012545 0 -20 3.7 43 0 VK7MOPVD3HZ -TE 16 1 5 2.2

012615 0 -20 2.0 -151 0 F2T 3 1 2 1.1

012645 0 -20 5.4 22 0 VK7MO VK3HZ -11 16 10 10 2.2

Good decode and audible but gave only -20 dB

012706 Transmitting: ISCAT- R-20

Good decode but not audible but gave -10 dB

012715 1 -10 7.0 0 0 * VK7MO VK3HZ -11 16 3 10 4.5

Note DF in Yellow is reducing as aircraft crosses

012745 0 -20 14.3 -129 0 XNG 3 1 1 1.1

012815 0 -20 10.9 -86 0 9WSJ0G2?A 10 0 2 1.1

012845 0 -20 2.0 -388 0 JDB 3 0 1 1.1

012915 0 -20 9.8 -86 0 9Q. 3 1 1 1.1

012945 0 -20 0.0 0 0 0 0 0 0.0

013015 0 -20 4.8 108 0 KL 2 0 1 1.1

013045 0 -20 10.4 86 0 /OVY 4 1 2 1.1

013115 0 -20 7.6 194 0 H5N8 L A 8 0 2 1.1

013145 0 -20 0.0 0 0 0 0 0 0.0

013215 0 -20 13.7 172 0 MD0X8R IN 9 0 3 1.1

013245 0 -20 9.8 345 0 H/U 3 0 1 2.2

The next looked promising with zero dF and 4 characters which with start of a message is consistent with RRR – VK3HZ was copying at this time so a plane was present

013315 0 -20 15.4 0 0 RUB 4 1 3 2.2

Next one is four characters but DF looks suspect

013345 0 -20 5.4 237 0 9N T 4 0 1 1.1

Again four characters and DF is possible

013415 0 -20 13.2 -65 0 JY5O 4 1 2 1.1

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024745 0 -20 7.0 -194 0 ERXEG 5 0 1 2.2

Finally after an hour and a quarter a Good RRR DF of zero and -11 dB

024815 1 -11 6.5 22 0 * RRR 4 2 4 8.9

024839 Transmitting: ISCAT- 73

024845 0 -20 12.6 -108 0 /RXH811 7 0 1 1.1

Overall took 3 hours to complete

As Rxed by VK3HZ

003228 Transmitting: ISCAT- VK7MO VK3HZ

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A nice burst but nothing heard at the other end

010830 1 -11 10.4 43 0 * VK3HZ VK7MO 12 8 10 8.9

010851 Transmitting: ISCAT- VK7MO VK3HZ -11

010900 0 -20 12.6 -258 0 DJG 3 1 2 1.1

010930 0 -20 8.7 22 0 VK3HZ VK7MO 12 2 5 15.6

011000 0 -20 7.0 0 0 VK3HZ VK7MO 12 6 10 8.9

011030 1 -7 3.7 0 0 * VK3HZ VK7MO 12 10 10 2.2

011100 0 -20 15.4 -237 0 Q23TI3/7 8 0 1 1.1

011130 0 -20 8.7 -22 0 CCFHZ VK7MO 12 0 2 8.9

A pair of aircraft in quick succession - this time a result

012430 0 -20 8.7 86 0 VK3HZ VK7MO 12 0 3 15.6

012500 0 -20 9.8 65 0 VKJHZ VK7MO 12 1 4 8.9

012530 1 -10 11.5 43 0 * VK3HZ VK7MO 12 10 10 8.9

012600 0 -20 3.7 43 0 VK3HZ VK7MO 12 2 6 4.5

012630 0 -20 12.0 323 0 DM- 4 0 1 1.1

012700 2 -6 4.2 0 0 * VK3HZ VK7MO 12 10 10 2.2

Heard a change of message, but manual decode needed to bring out the report

012700 0 -20 14.1 0 0 R-20 5 6 10 1.7

012726 Transmitting: ISCAT- RRR

012730 0 -20 0.0 0 0 0 0 0 0.0

012800 0 -20 7.6 -22 0 R-20 5 0 3 8.9

012830 0 -20 3.7 -366 0 AHE 3 1 1 1.1

012900 0 -20 14.3 258 0 M?O 3 0 1 1.1
012930 0 -20 15.4 366 0 2KD 3 1 2 1.1
013000 0 -20 13.7 108 0 3SV181WKNMOB7EGIX 17 0 4 1.1
013030 0 -20 2.0 323 0 S?2XQ-3CLH 10 0 3 2.2
013100 0 -20 5.9 -301 0 9U7 4 0 1 1.1
013130 0 -20 7.0 345 0 JN? 3 0 2 1.1
013200 0 -20 3.1 108 0 A?6D 5 0 3 1.1

Second aircraft

013230 0 -20 3.7 43 0 R-20 5 5 9 4.5
013300 0 -20 4.8 22 0 R-20 5 1 4 4.5
013330 1 -9 5.9 0 0 * R-20 5 8 10 4.5
013400 1 -8 8.1 0 0 * R-20 5 9 10 2.2
013400 0 -20 8.7 0 0 R-20 5 3 10 1.1
013400 0 -20 13.0 323 0 RI80H7 6 0 1 1.1

Finally

024830 0 -20 11.8 0 0 R-20 5 2 3 1.7

Again heard a change of message, but manual decode needed to bring out the 73

024830 0 -20 12.9 0 0 73 3 4 6 1.7
024900 0 -20 12.0 -108 0 --UDHD6BF5US U 14 0 3 1.1
024921 Transmitting: ISCAT- 73
024930 0 -20 2.6 -258 0 PM8 3 1 2 2.2
025000 0 -20 10.4 -86 0 73 3 0 1 8.9

Decoding in relation to Power

From the results it is noted that VK7MO received only 3 fully correct decodes from the 4 watts transmitted by VK3HZ, whereas VK3HZ received some 18 fully correct decodes from the 20 watts transmitted by VK7MO. So the power difference seems to make a significant difference to the result.

Doppler Variation as seen in Results

Good Doppler was over a relatively limited range of +86 to -86 Hz compared to over 200 Hz that we get at 10 GHz. As the Doppler should increase in proportion to frequency one would expect for the same range of scattering angle up to 500 Hz of Doppler at 24 GHz. Now it is possible that the narrower antenna beamwidths are limiting the extremes of Doppler but we suspect that the limitation is more likely due to the fact that we are working on lobes in the horizontal plane which are now much more closely spaced and only the very central lobes are useful. If this is the case then the bandwidth limitations of ISCAT-B (which uses almost the full SSB passband) are not of concern and ISCAT-B is the preferred mode at 24 GHz as it can take advantage of the much shorter bursts of signal. Noting that ISCAT-B can decode a 1.1 second burst compared to 2.2 seconds required for ISCAT-A.

Period of Transmission

ISCAT offers the facility to operate in 15 second or 30 second periods. To have any chance of getting more than one over through on a single aircraft it is necessary to use 15 second periods.

Swipe Decoding

ICSAT has a facility to swipe along the waterfall in the main window to focus on a small section in which the signal is stronger and this sometimes improves decoding. This facility can also allow the decoding of a different message if the transmitting station changes the message during transmission – as is almost always the case as there is less than a second from the time one gets a decode to the time transmission starts. VK3HZ was able to use this facility effectively to decode the first R-20 report at the end of a period that started with Callsigns and Report (see two separate decodes at 122700 in the results above). He used it again to pick up a change from R-20 to 73 in period 024830. Fig 1 is and example of swipe decoding.

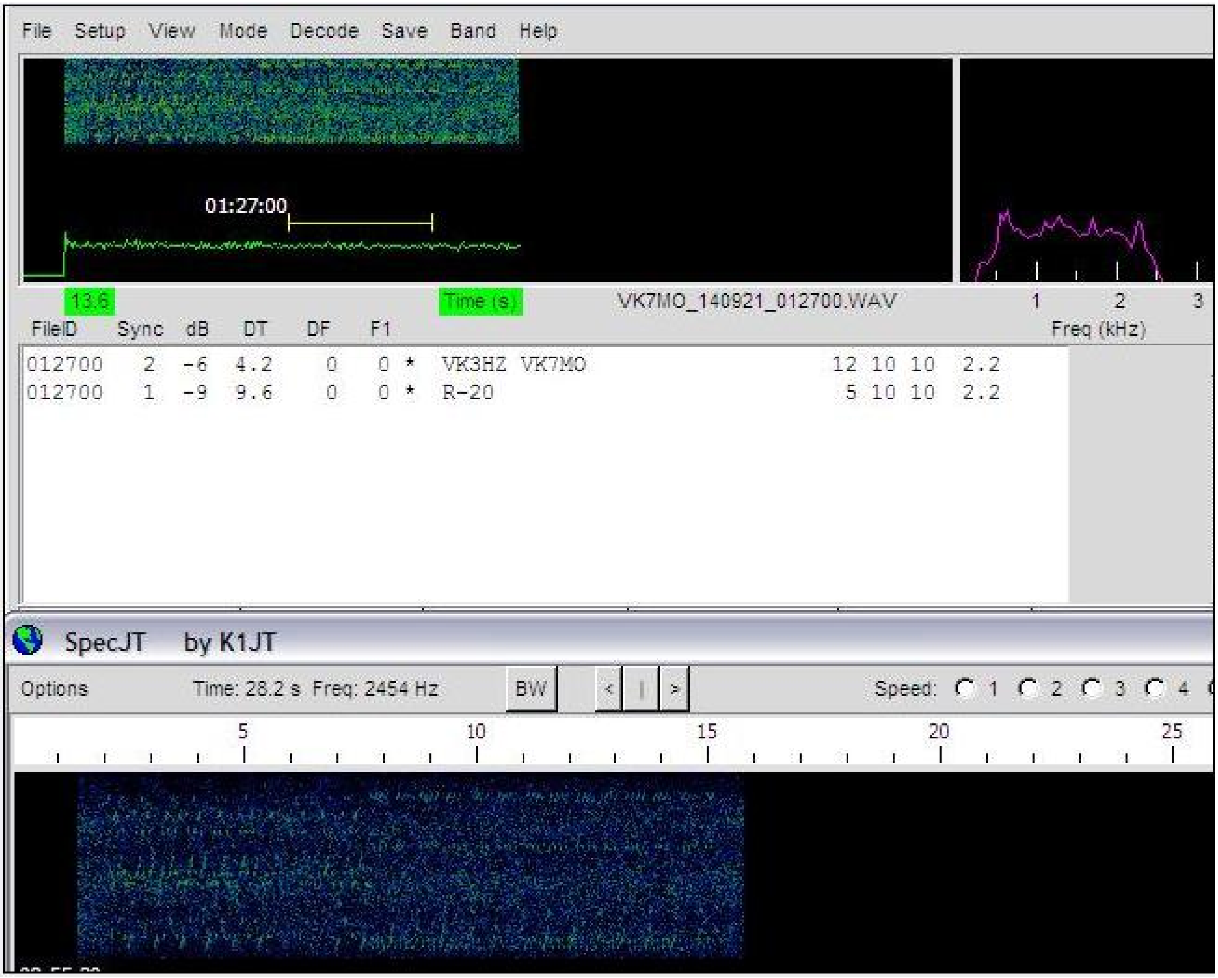

Fig 1: Example of Swipe Decoding. If you look carefully at the bottom waterfall you can see a change in the tone pattern at about 7.5 seconds. The program originally decoded from the first period but by using swipe in the second period it is seen that there is a change to sending a report.

Note that the use of swipe decoding when running 15 second periods requires one to be totally on the ball during a QSO that may as in this case take up to 3 hours. Watching the positions of aircraft on ADSB in relation to crossing the path of propagation helps make sure you are paying attention at the time a decode is likely.

Signal Strength Reports on ISCAT

As reported above there were situations where the signals were audible that gave a report of -20 dB and another that was not audible that gave -10 dB. It is also possible to use swipe decoding on sections of files that give quite different signal strength reports. So in fact the reports are not all that meaningful, but they do ensure that unknown information is exchanged to meet the requirements of a QSO.

CONCLUSIONS

At the VK7MO end, copy only occurred when the aircraft were up around 40,000 feet giving less atmospheric losses. From these tests it is clear that beaming accuracy in both azimuth and elevation are critical and that we need to pay much more attention to beaming accuracy based on knowledge of the aircraft height as it crosses the path of propagation. We did not do this for earlier long distance tests where we just beamed slightly above the horizon and this could have contributed to the failures.

The surprising thing was that despite an improvement of over 30 dB in system performance our range has only gone up from 461 km to 566 km. It seems atmospheric losses have far greater affect than we expected, perhaps combined with beaming accuracy.

While at 10 GHz aircraft scatter is essentially only limited by needing radio line of sight to an aircraft crossing the path of propagation at 24 GHz atmospheric losses are the limitation. In a similar way to what has been found at EME (by VK7MO, OK1KIR & G3WDG) low elevations kill 24 GHz.

We suspect that at 566 km we are near the limit of our present systems for aircraft scatter at 24 GHz but future tests will need to focus on improving beaming accuracy if any improvement is to be gained.